A Review for the US Navy of Best Practices, Knowledge and Data Gaps, and Research Directions for Vapor Intrusion

Todd McAlary and Robert Ettinger, Geosyntec Consultants
Paul Johnson, Arizona State University
Bart Eklund, URS
Heidi Hayes, Air Toxics Limited
Tim Shields, Richard Brady Associates
Bart Chadwick and Ignacio Rivera-Duarte, SPAWAR Systems Center Pacific

Environment, Energy and Sustainability Symposium
Denver, May 2009

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **MAY 2009**	2. REPORT TYPE	3. DATES COVERED **00-00-2009 to 00-00-2009**

4. TITLE AND SUBTITLE **A Review for the US Navy of Best Practices, Knowledge and Data Gaps, and Research Directions for Vapor Intrusion**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Geosyntec Consultants,427 Princess Street, Suite 429,Kingston, ON K7L 5S9,**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Presented at the NDIA Environment, Energy Security & Sustainability (E2S2) Symposium & Exhibition held 4-7 May 2009 in Denver, CO. U.S. Government or Federal Rights License

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**31**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Scope

- Conduct desk-top study to improve vapor intrusion pathway assessments at Navy sites
  - Review and document best practices
  - Identify technology and knowledge gaps
  - Recommend areas for focused research
- Develop an integrated strategy for cost-effective reduction of the overall uncertainty

Focus Areas

- Technically defensible sub-surface sampling



- Passive air sampling methods

$$F = A \times D \times (\delta C/\delta x)$$

- Distinguish background vs vapor intrusion sources





Current Best Practice

Common VI Investigation Approach:

1) Select VI Guidance Document (from dozens)
2) Collect and analyze samples of various media
3) Compare concentrations to screening levels

- Often ambiguous outcomes:
  - spatial and temporal variability
  - background sources
  - data biases and gaps

Sampling

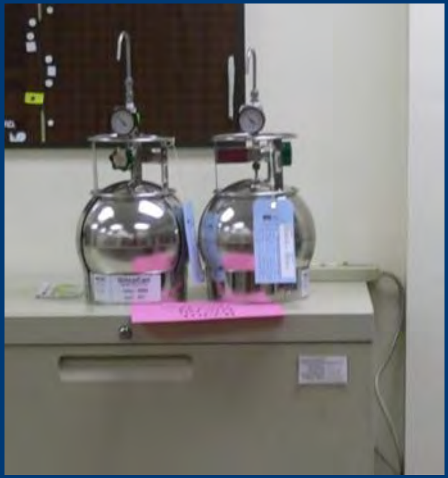
Groundwater

Bulk Soil

Near-Slab Soil Gas

Sub-Slab Soil Gas

Indoor Air



Outdoor Air

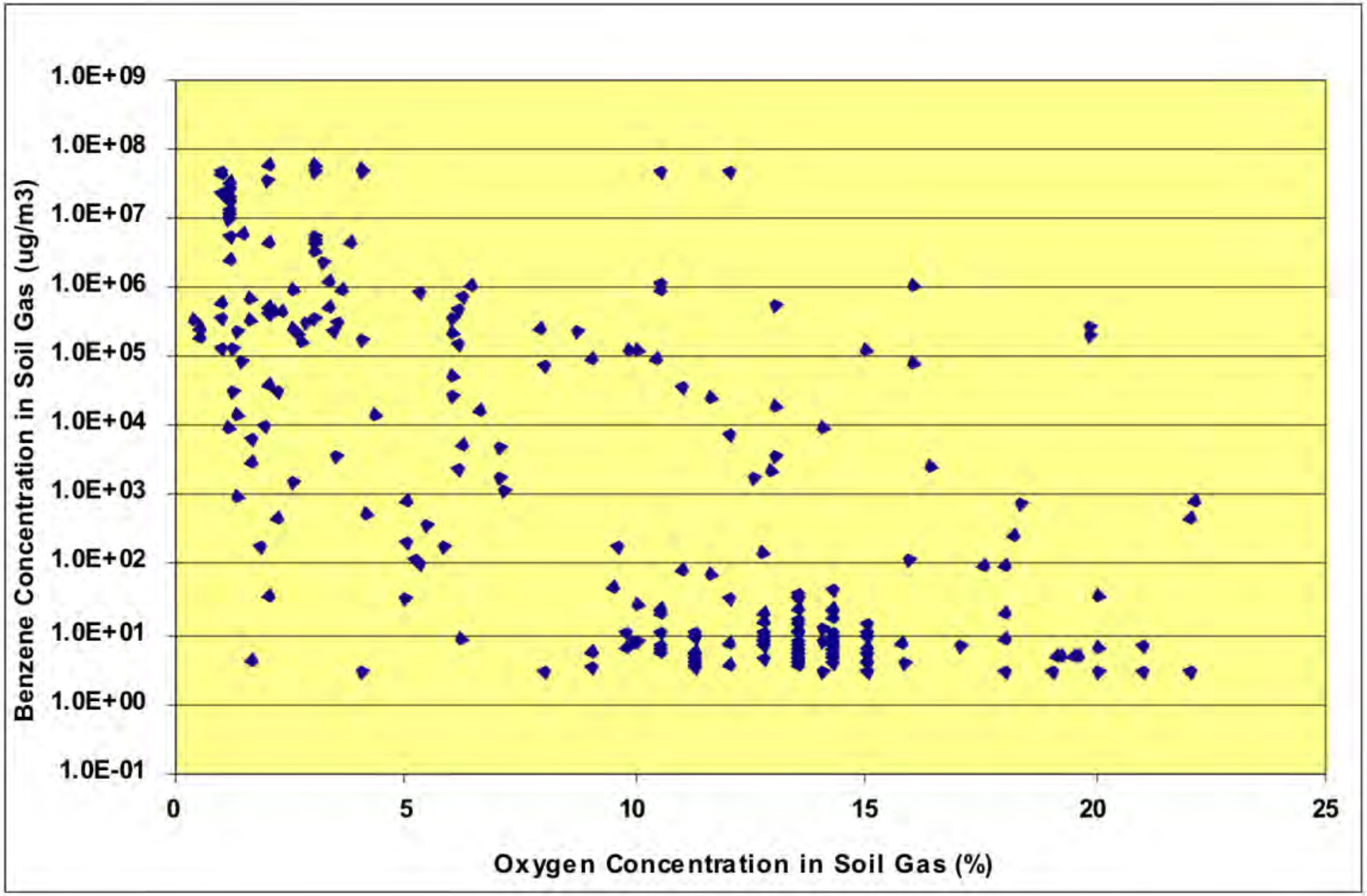
None are perfect, some less than others

Matrix for Guidance on Selection of Soil Gas Sampling Methods with Compatible DQO Results

(GeoProbe Systems, Technical Bulletin No. MK3098, May 2006)

Downhole Sampling System		Sample Collection Method			
		Syringe	Tedlar Bag	Glass Bulbs	Summa Canister
	Increase Quality				
Direct Sampling		Low/Low			Low/High
PRT System					
Implants					
Gas Wells		High/Low			High/High

Data Quality



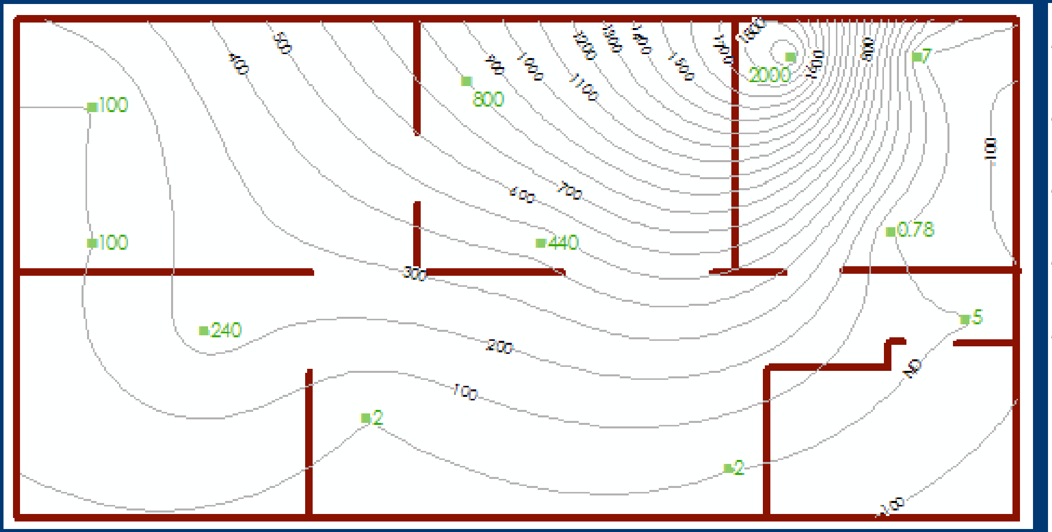
High concentrations of both benzene and oxygen in the same soil gas sample is unexpected.

Were there leaks?

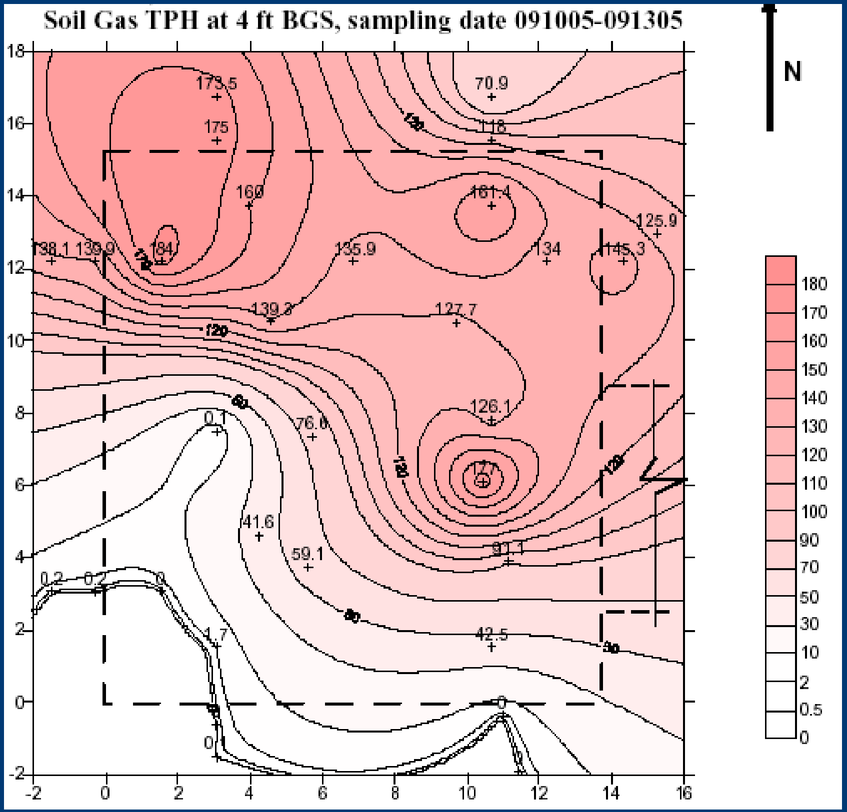
(Courtesy API)

Geosyntec consultants

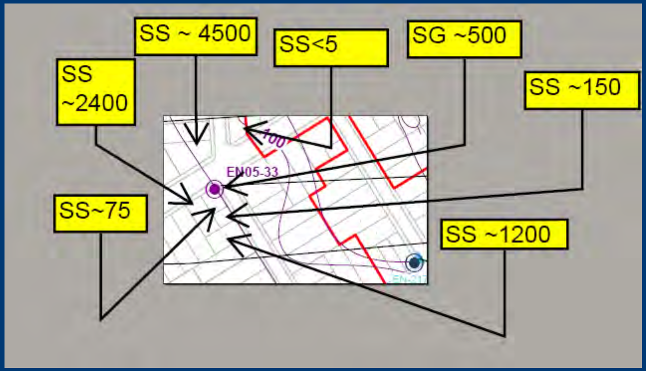
Spatial Variability



(McAlary et al., 2007)



(Luo et al., 2006)

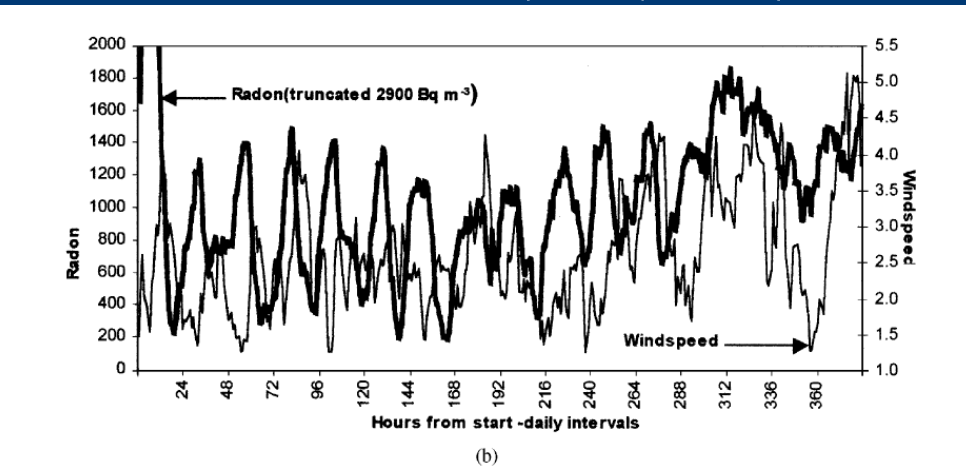


(Wertz, 2006)

Several orders of magnitude range in concentrations

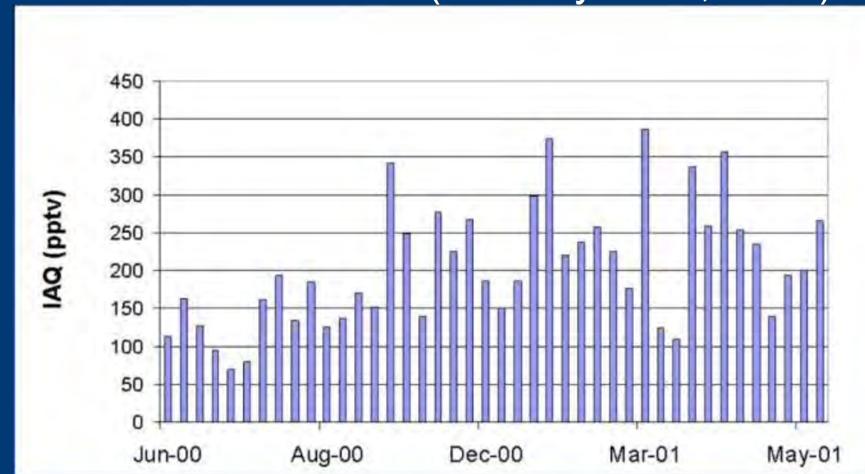
Temporal Variability

Indoor Air Radon (Marley, 2001)

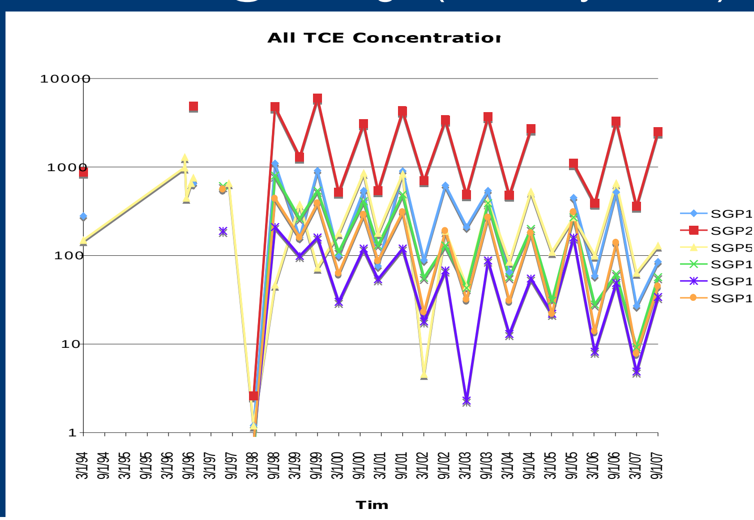


(b)

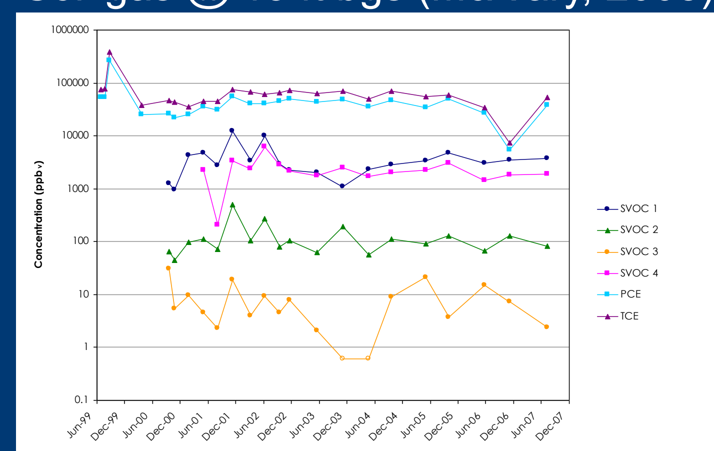
Indoor Air VOC (McAlary et al., 2002)



Soil Gas @ 5 ft bgs (McAlary, 2008)

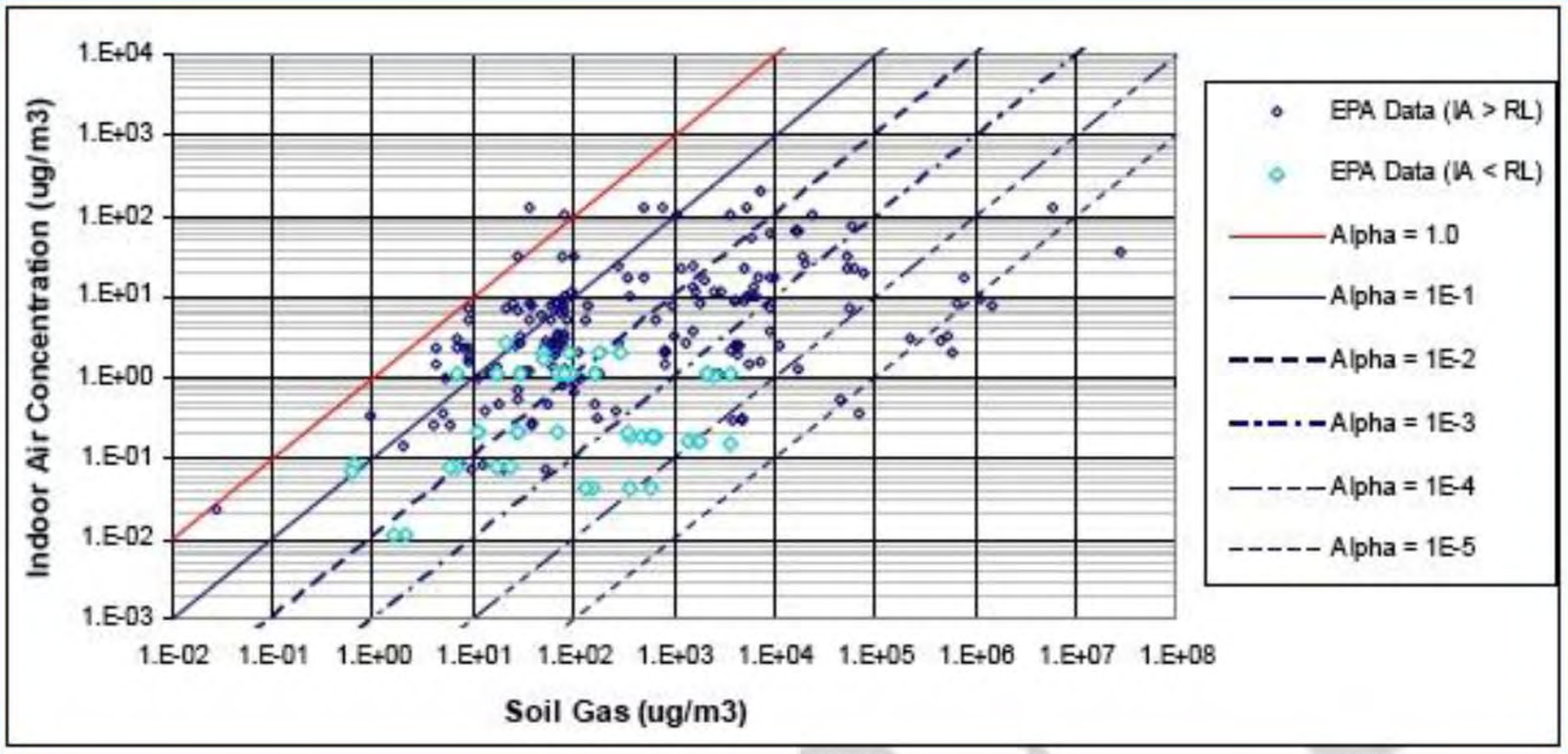


Soil gas @ 15 ft bgs (McAlary, 2008)



Geosyntec consultants

EPA Database of Soil Gas Data



Is there really any correlation? Why so poor?

(Dawson, 2008)

Geosyntec consultants

Variability in Screening Levels

Table 3. Residential Screening Levels for Selected VOCs

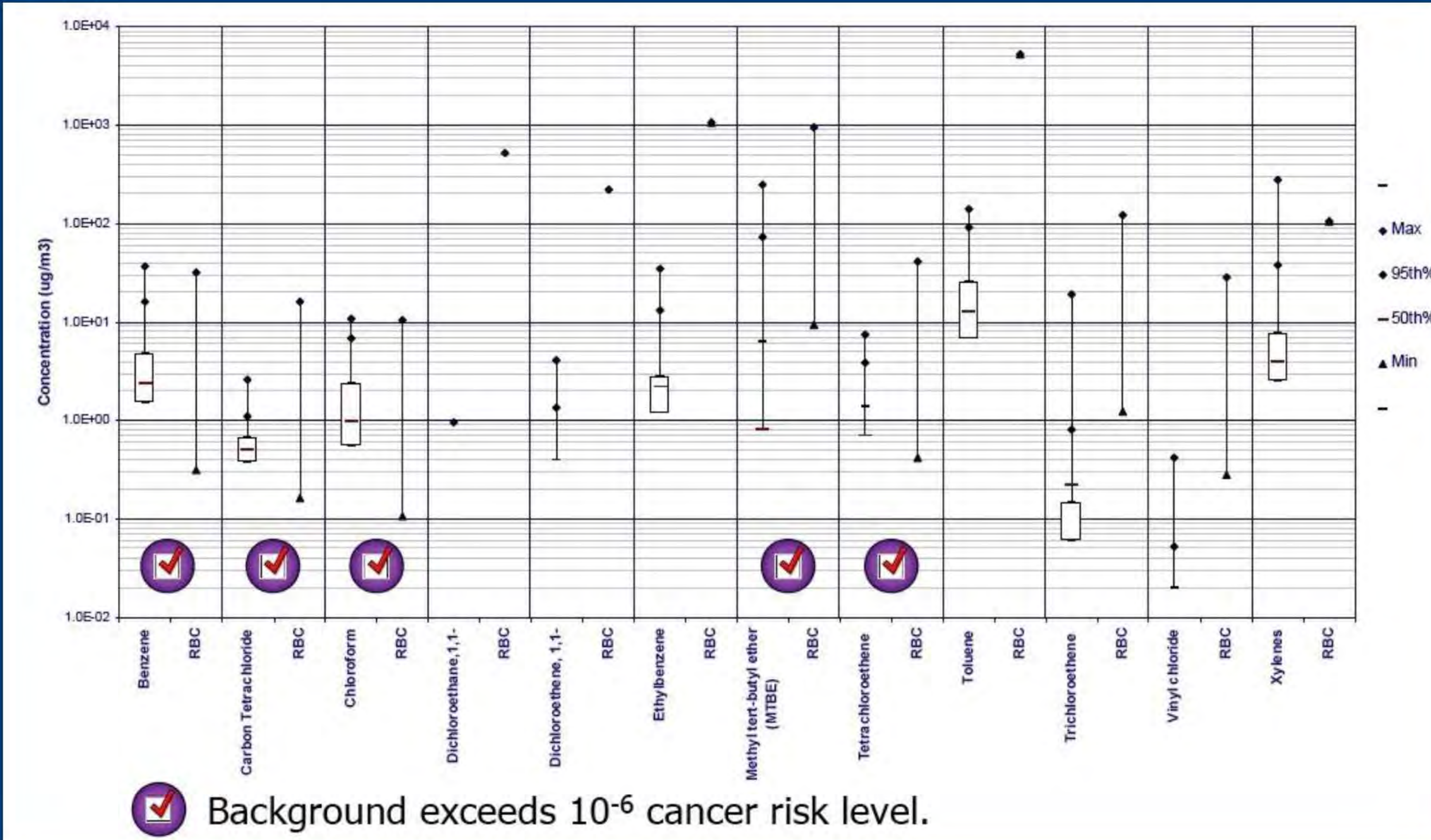
State	Benzene			TCE			PCE		
	Ground Water	Soil Gas	Indoor Air	Ground Water	Soil Gas	Indoor Air	Ground Water	Soil Gas	Indoor Air
Alaska	5	3.1	0.31	5	0.22	0.022	5	8.1	0.81
California	NA	36.2	0.084	NA	528	1.22	NA	180	0.41
Colorado	15	NA	0.23	5	NA	0.016	5	NA	0.31
Connecticut	130	2,490	3.3	27	752	1	340	3,798	5
Indiana	95-850	250 - 1400; 25 - 140[a]	2.5	4.6 - 700	120 - 2000; 2 - 200[a]	1.2 - 4.1	7.4 - 1100	320 - 5200; 32 – 520[a]	3.2 - 10
Louisiana	2,900	NA	12	10,000	NA	59	15,000	NA	110
Maine	NA	NA	10[b]	NA	NA	NA	NA	NA	NA
Massachusetts	2,000	NA	0.3	30	NA	1.37	50	NA	0.04
Michigan	5,600	150	2.9	15,000	700	14	25,000	2,100	42
Minnesota	NA	1.3-4.5	1.3-4.5	NA	NA	NA	NA	NA	20
New Hampshire	2,000	95	1.9	50	54	1.1	80	68	1.4
New Jersey	15	16	2	1	27	3	1	34	3
New York	NA	NA	NA	NA	NA	5	NA	NA	100
Ohio	14	31	3.1	--	122	12.2	11	81	8.1
Oklahoma	5	3.1	0.27	5	0.17	0.017	5	0.33	0.33
Oregon	160	NA	0.27	6.6	NA	0.018	78	NA	0.34
Pennsylvania	3,500	NA	2.7	14,000	NA	12	42,000	NA	36

Notes:
1. Units are µg/L for groundwater and µg/m^3 for soil gas and indoor air
2. See individual state guidance documents for additional information, including limitations and exceptions
3. Trigger or action levels for mitigation based on indoor air concentrations may be higher than the screening levels shown.

[a] Second range of values shown is for sub-slab soil gas.
[b] Chronic exposure value.

(Eklund, 2007)

Background vs Target Levels

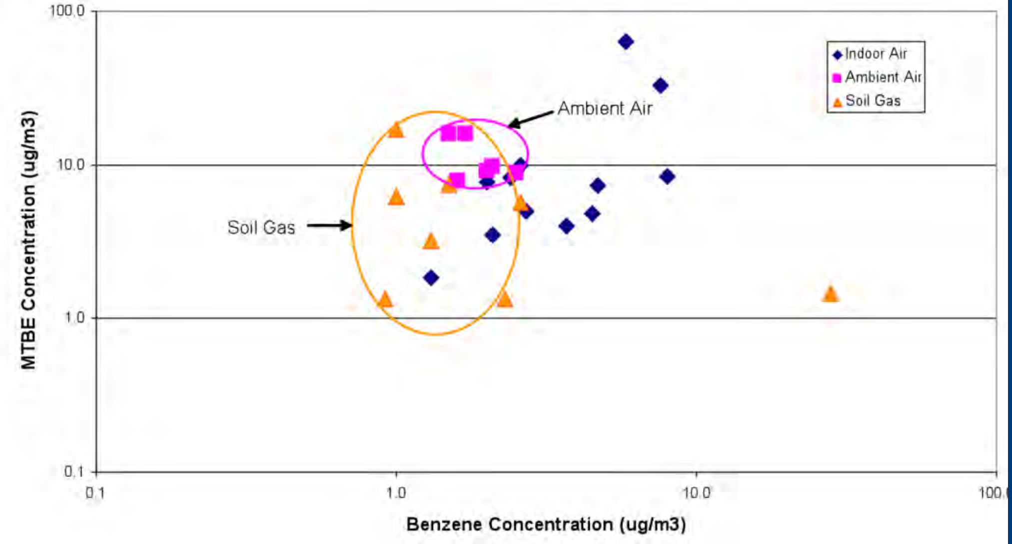


USEPA, 2008

(MTBE background has been dropping faster than others)

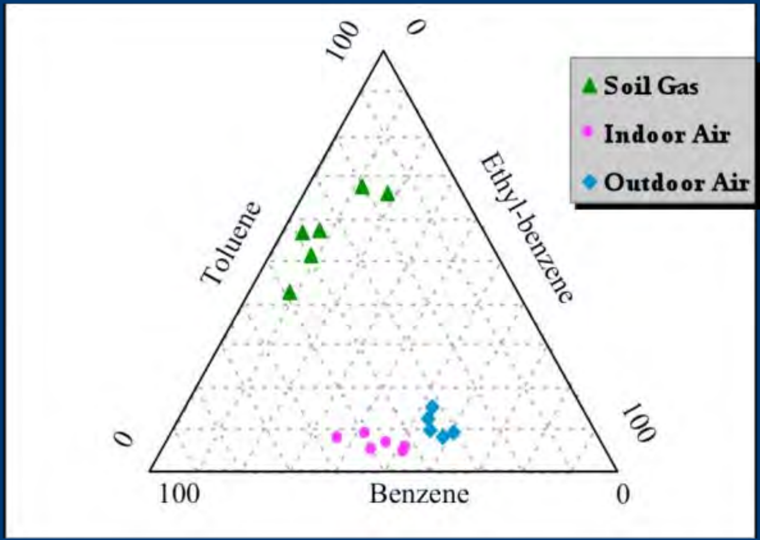
Resolving Background

Compound Ratios (MTBE vs Benzene)

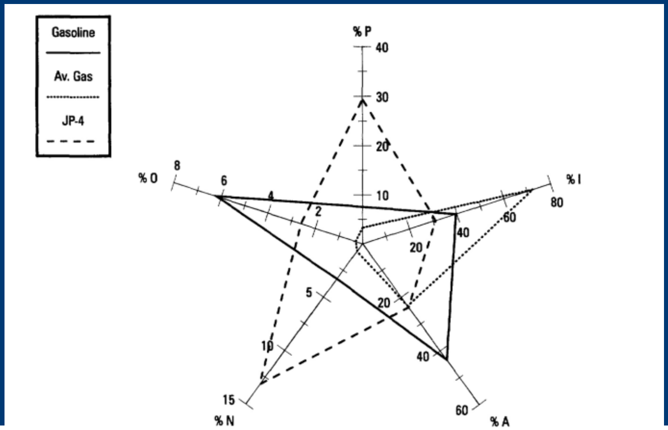


(Berry-Spark et al., 2004)

Trilinear Plots



(McAlary and Dawson, 2005)



Compound ratio plots from sub-surface and indoor air samples may help distinguish interior sources

Multi-linear diagrams

(Kaplan, et al., 1997)

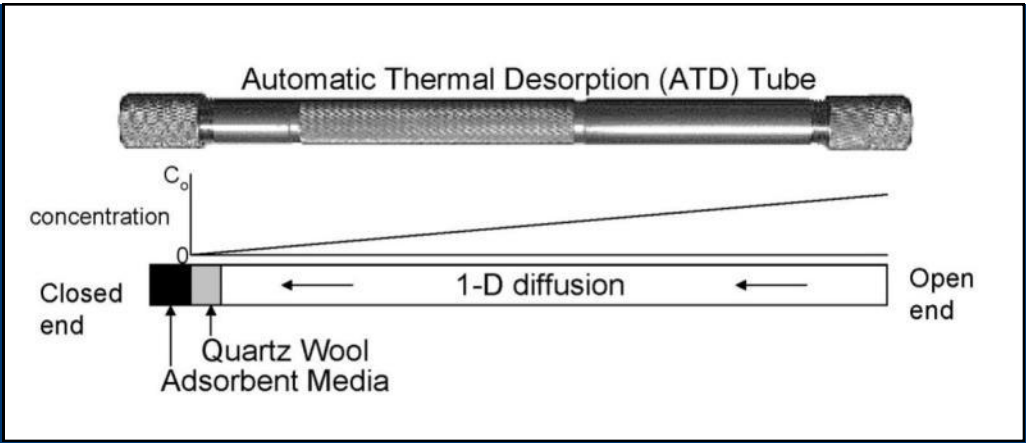
Summary of Current Best Practices

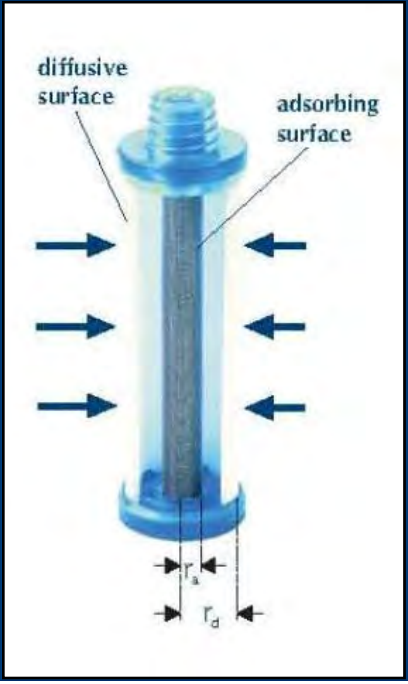
- Current approaches often result in uncertainty
  - Spatial and temporal variability, positive and negative bias
- Uncertainty can be managed with LOTS of data
  - Gets expensive, and doesn't necessarily resolve issues
- Background is almost always a challenge
  - Not always easily resolved
- Some new approaches are being tested on an *ad hoc* basis, but more formal studies need to be done to facilitate regulatory approval

Research Directions

- New techniques and tools to minimize variability
- Real-time information
- Less expensive investigative tools
- Field demonstrations at "typical" sites
  - Shallow Water Table (common for Navy)
  - Large Slab-on-Grade Buildings
  - Undeveloped Land
  - Etc.

Passive Samplers (Temporal Integration)





ESTCP Project 08 EB ER3-036 will compare 4 passive samplers to establish capabilities and limitations:

1) SKC Ultra II™ Badges

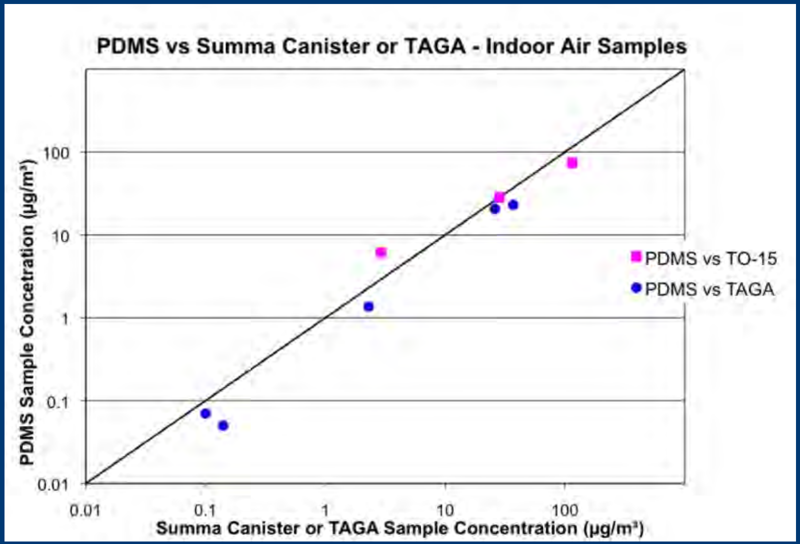
2) Perkin Elmer Tubes

3) PDMS Membrane samplers

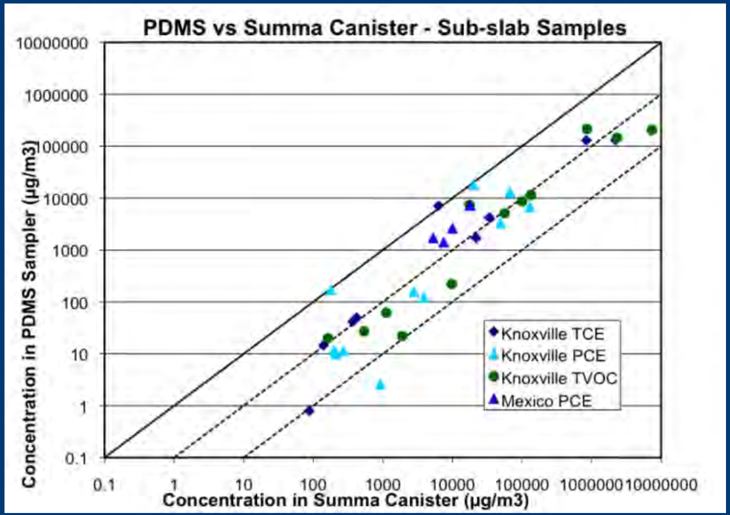
4) Radiello™

Passive vs Active Sampling

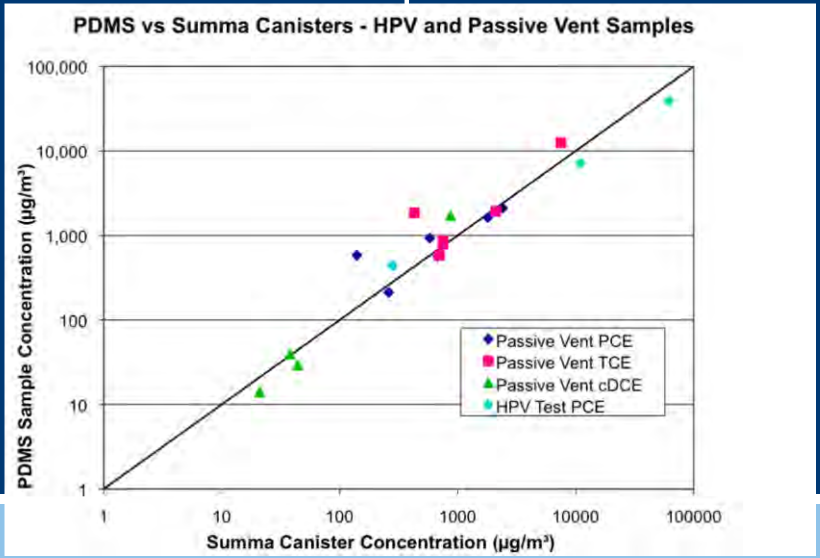
Indoor Air



Sub-Slab



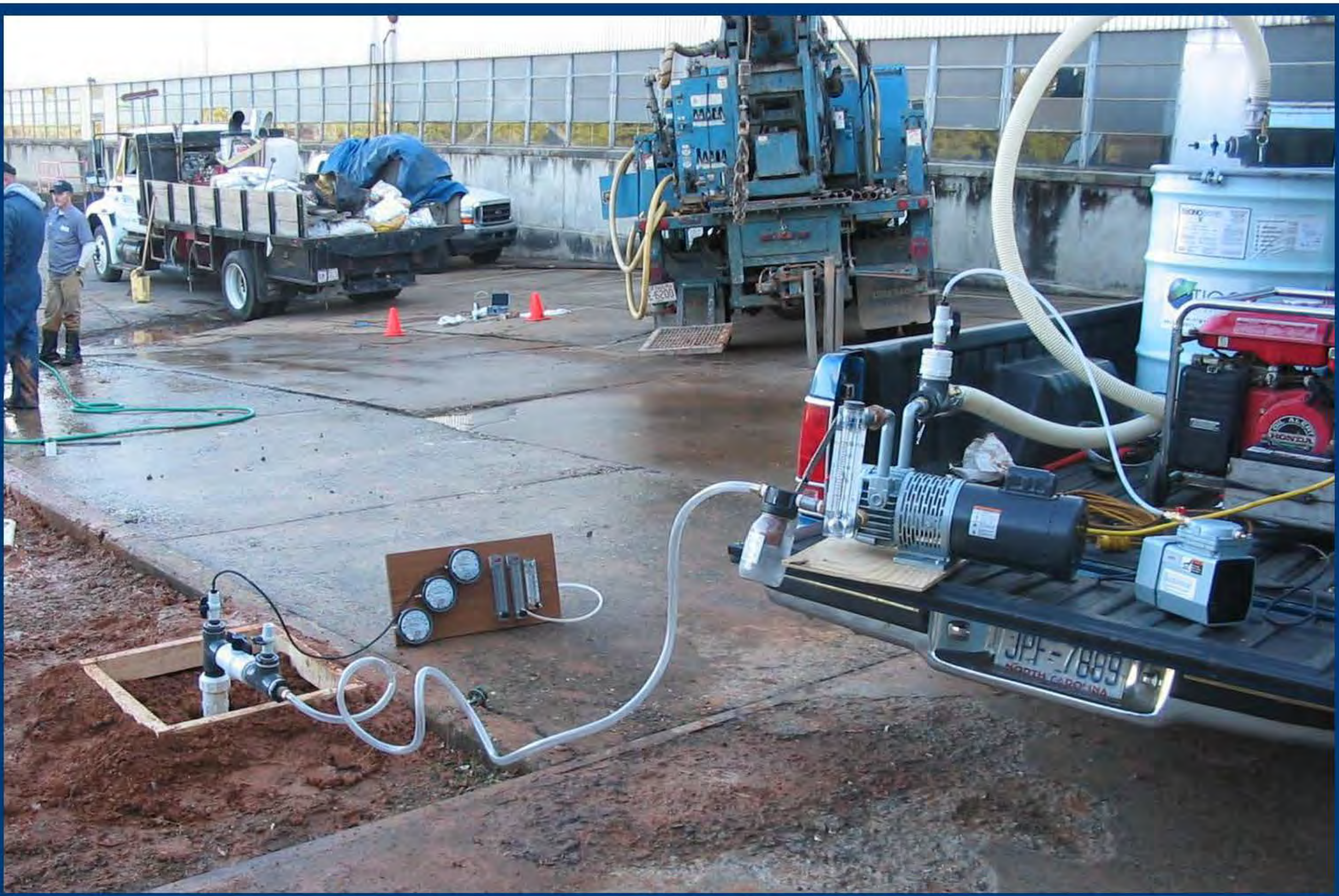
Vent-Pipes



Comparison to conventional methods is encouraging for samplers where the uptake rate is controlled and quantified (not all passive samplers do this)

(McAlary et al., 2009)

High Purge-Volume Sampling (Spatial Integration)

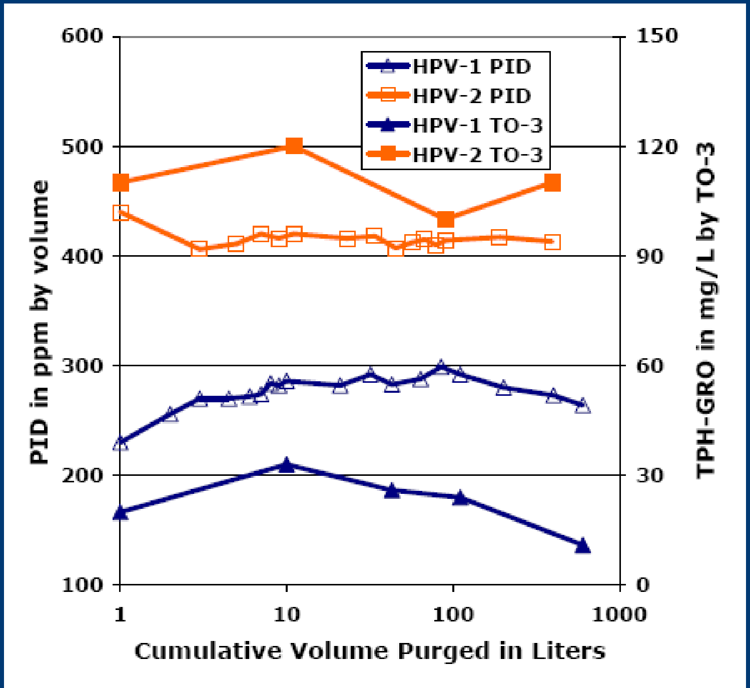


Buildings “inhale” about 0.1 to 10 L/min of soil gas = 1.6 to 160 million L over 30 years

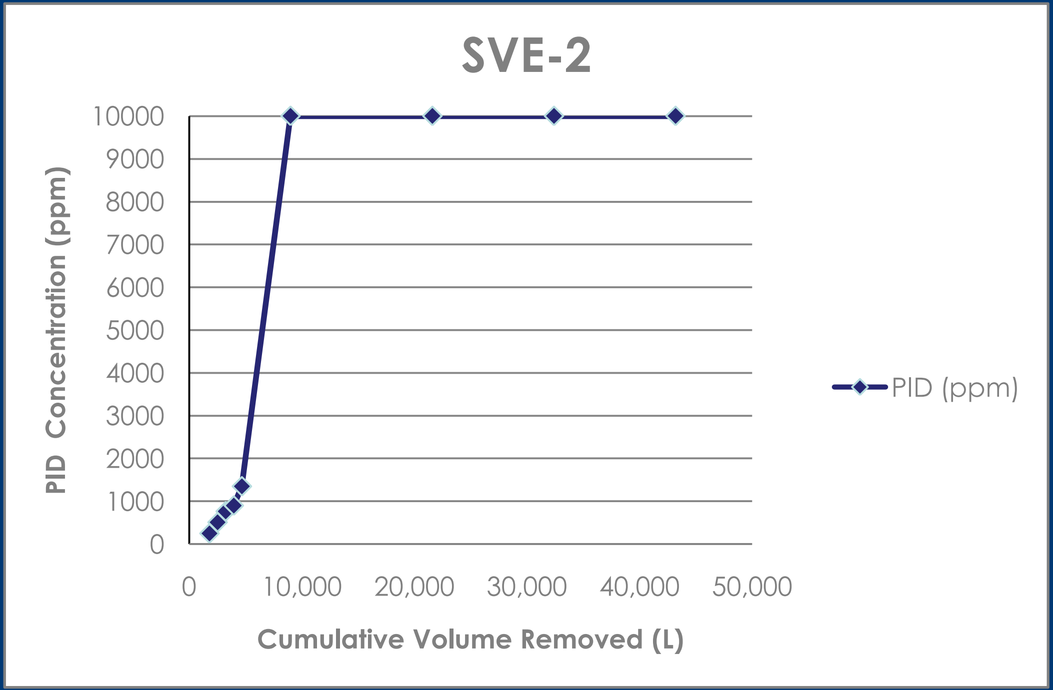
Is a 1L soil gas sample a “representative elemental volume”? Why not 1,000 L? Or 10,000 L?

Geosyntec consultants

High Purge-Volume Test Data



(Creamer and McAlary, 2009)



Trend in Concentrations vs Volume Removed can help to elucidate location of source

Geosyntec consultants

Real-Time Portable Monitoring

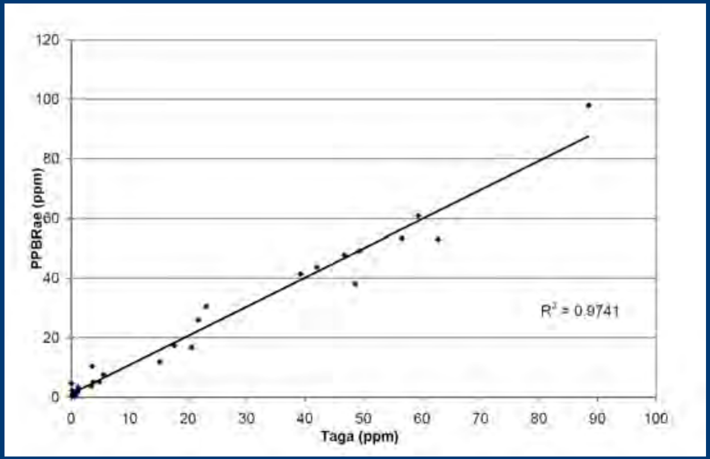
ppbRAE

HAPSITE Viper

Foxboro TVA 1000 FID/PID

Tiger Microfast GC

PID vs TAGA



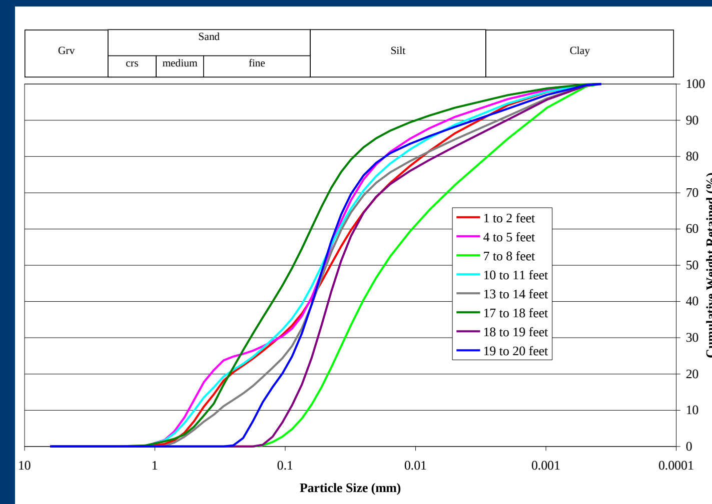
(MSRAS, in press)

Capabilities and limitations?

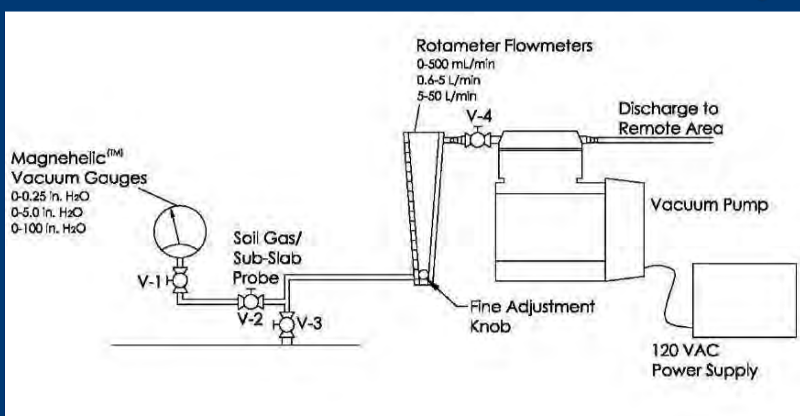
Soil Properties

Coring and Visual Inspection

Particle Size Distribution



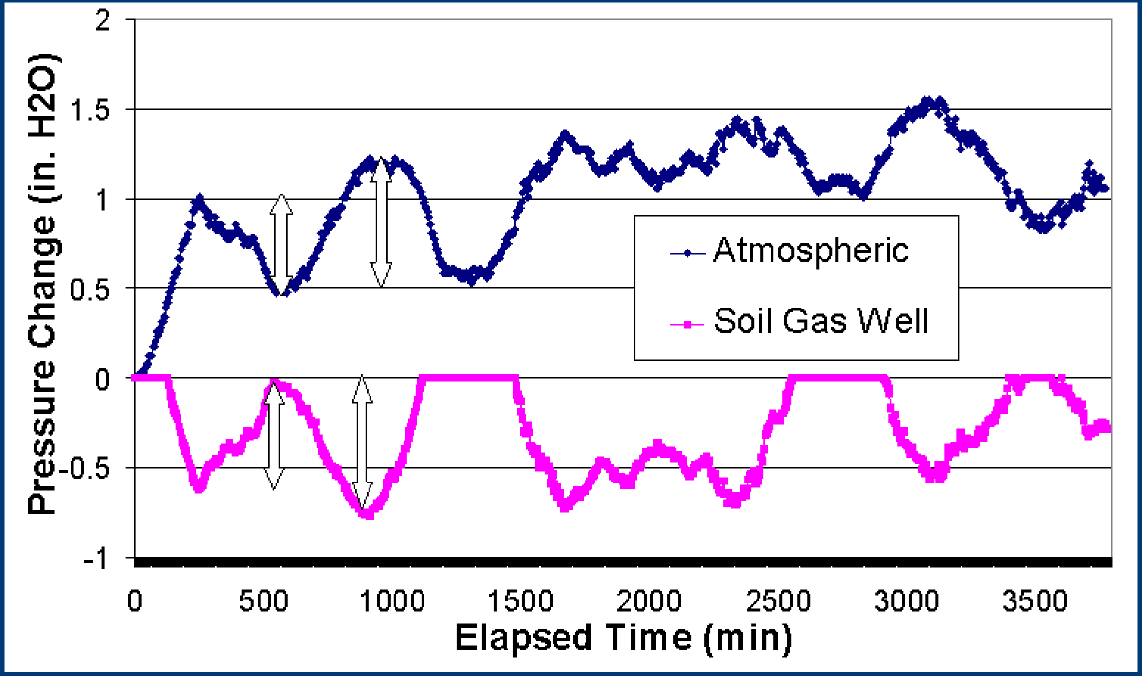
Flow, Vacuum and Permeability



Porosity and Moisture Content

To what extent do sampling methods depend on the soil type?

Meteorological Data

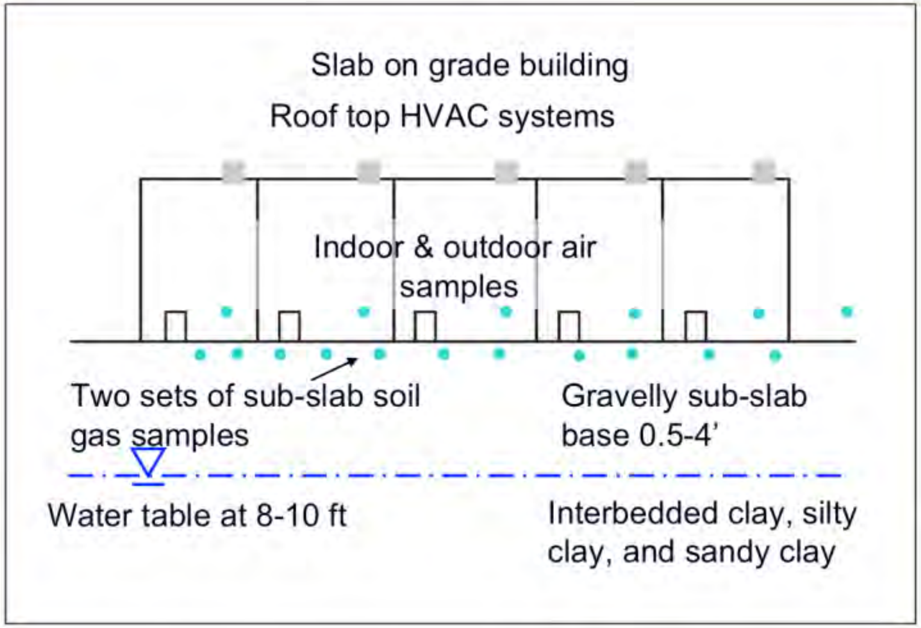


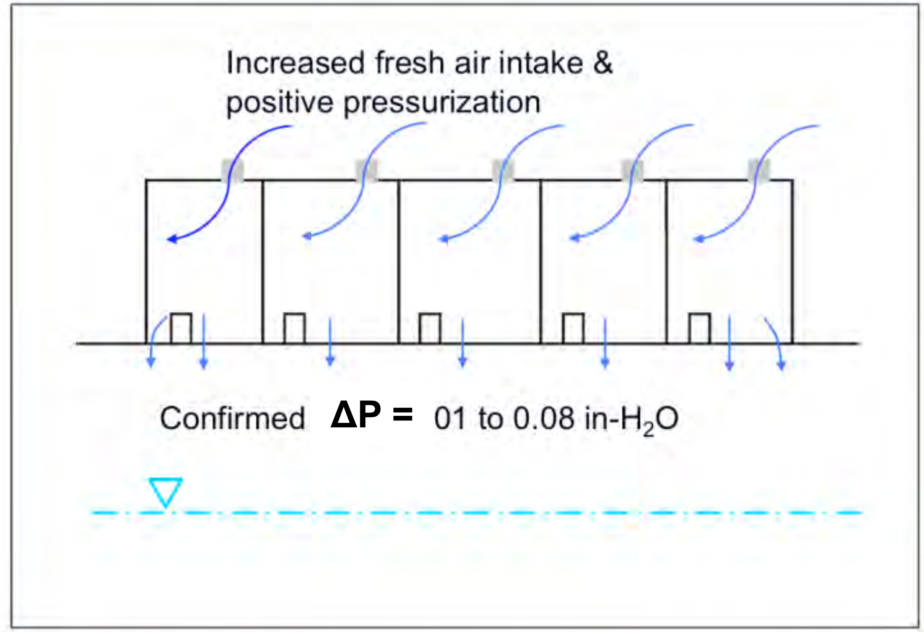
Monitor Barometric Pressure and Gauge Pressure in a deep soil gas probe

If the Gauge Pressure is a mirror image of the Barometric pressure over time, deep soil gas MUST be pneumatically isolated from the atmosphere

(McAlary, 2003)

Pressure Cycling Strategies





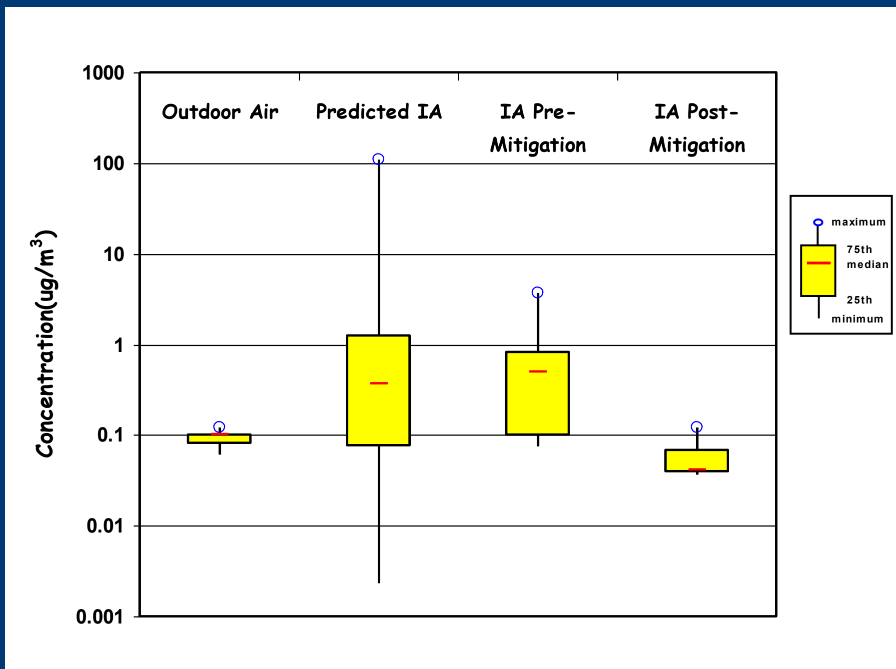
(Berry-Spark et al., 2005)

Sample Building under Positive and Negative Pressure

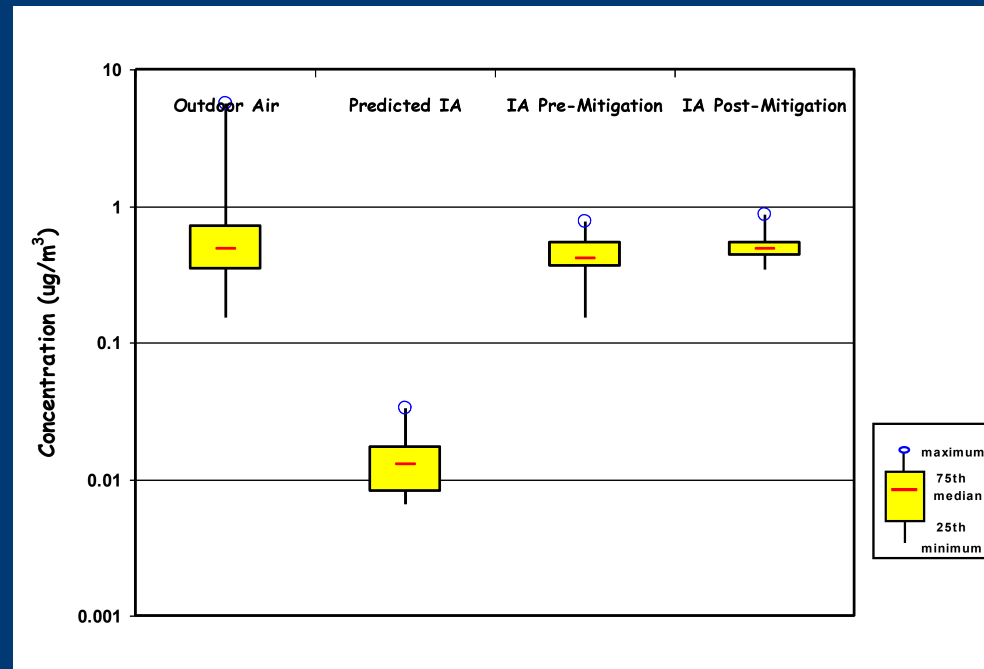
positive pressure will reduce or eliminate vapor intrusion

Pressure Cycling Strategies

TCE



Benzene



(Berry-Spark et al., 2005)

Indoor Air concentrations were initially similar to predictions from soil gas data

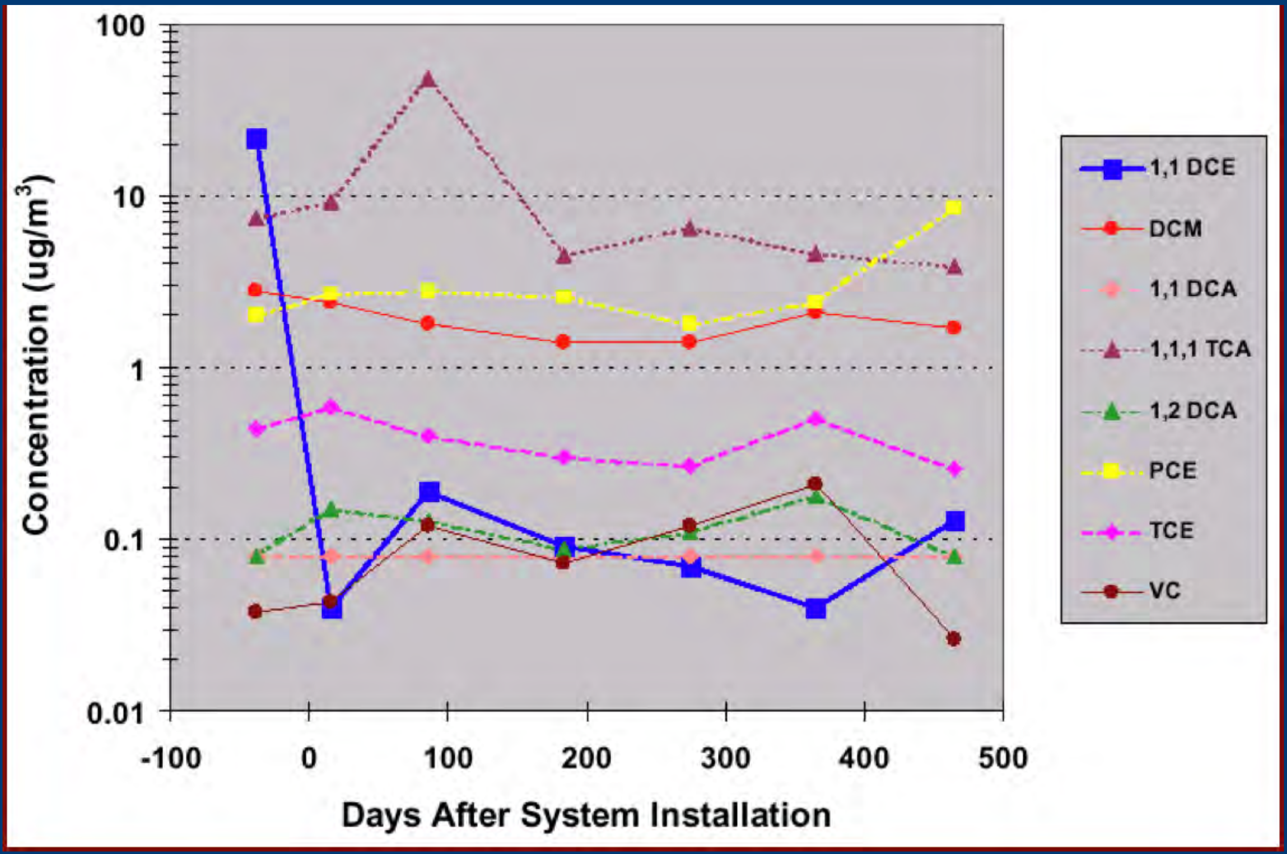
Indoor Air concentrations were initially similar to outdoor air concentrations

>10X drop after building pressurized

No change when building pressurized

Geosyntec consultants

Pressure Cycling



(Folkes, 2000)

Classic response of indoor air concentrations to sub-slab depressurization

1,1-DCE concentrations dropped by >100X

Other compounds unchanged (interior sources)

Building HVAC Characterization

Pressure/Ventilation Testing
Test and Balance Reports

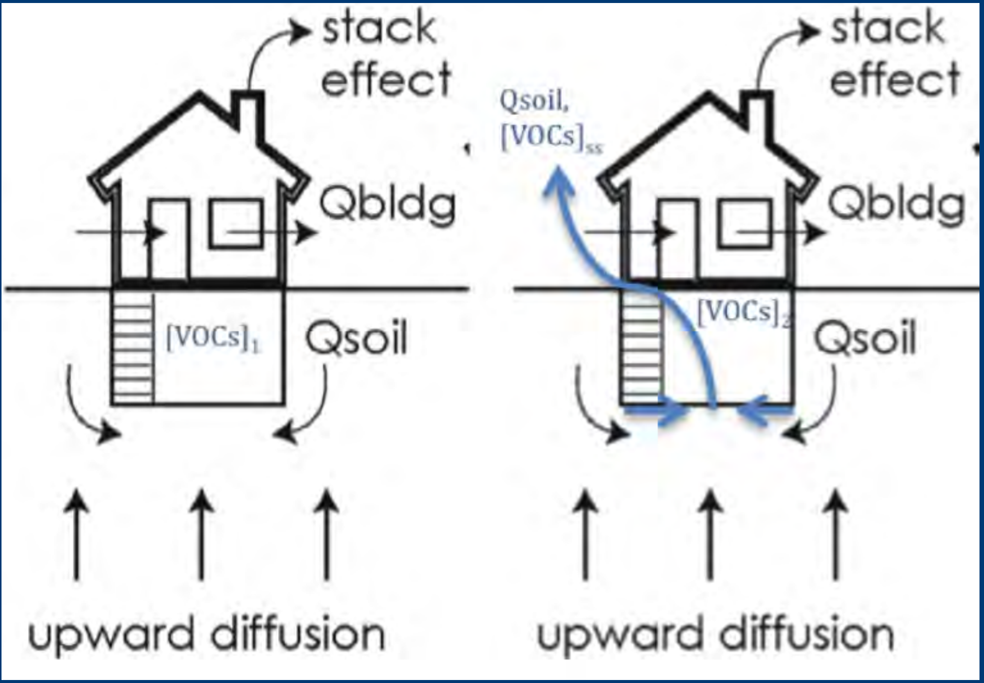
Cross-Slab Pressure

Smoke Pen

Electromagnetic Flowmeters

Building pressure is often influenced by the ventilation system, and can have a dramatic effect on vapor intrusion.

Building Flux Monitoring



$$F = Q_{soil} \times [VOCs]_{ss}$$

$$[VOCs]_{VI} = F/Q_{building}$$

$$[VOCs]_{VI} = [VOCs]_1 - [VOCs]_2$$

Mostly, we measure concentrations (it is easier)

But if we could measure flux, it might actually be more relevant

Key issue is the scale of measurement

can we use the whole building as a flux chamber?

Additional Research Opportunities

- Extended Flow Controllers for Canisters

  Indoor air samples from 1 day to 7 (temporal average)

- Composite Sampling

  Collect aliquots from multiple locations (spatial average)

- Compound-Specific Stable Isotope Analysis

  Look at C^{13}/C^{12} to assess degradation (fingerprinting)

- Use of Radon as a Tracer

  where present naturally (building-specific α-factor)

Geosyntec consultants

Summary

- Current best practice often leads to uncertainty or ambiguity
  - Temporal and spatial variability
  - Very low target levels (analytical challenges and biases)
  - Background interferences
- Several emerging methods may help to reduce uncertainty and cost
  - Temporal and spatial integration
  - Manipulating Building pressure – use the building like a flux box
  - New hardware – lower detection limits, greater portability, lower cost
  - Forensic tools and Tracers
- Research is needed to demonstrate the capabilities and limitations
  - Detailed studies of selected sites or buildings
  - Comparative studies between technologies

Recommendations from Navy Panel

1) Passive sampling devices:

Quantitative evaluation of average concentration,

Differentiation between background and VI, and

Regulatory acceptance

2) Pressure cycling for evaluation of background:

Development of a practical & reliable SOP

3) Portable GC-MS:

Quantification issues

Regulatory acceptance

Acknowledgements

SPAWAR Systems Center Pacific

Code 71750

53475 Strothe Rd.

San Diego, CA 92152